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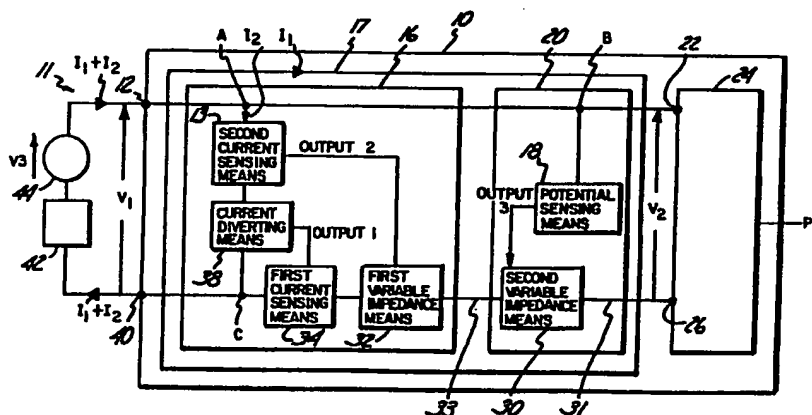
With international search report.

See US 5,179,488

(54) Title: PROCESS CONTROL INSTRUMENT WITH LOOP OVERCURRENT CIRCUIT

## (57) Abstract

A process control instrument (10) receiving a DC current from a two wire loop (11, 43) having overcurrent protection (16, 52) and reverse current protection (20, 54) circuits interposed between a two wire loop (11, 43) and a process control device (24) for reducing the incidence of damage or degradation to the process control device (24) from excessive and reverse polarity currents from the loop. The overcurrent protection circuit (16, 52) comprises device current flowing through a first current sensing circuit (34, 60) which generates a first output which controls impedance of a current diverting circuit (38, 62). The impedance of the current diverting circuit controls the flow of a shunt current shunted back to the two wire loop (11, 43). Shunt current flowing through a second current sensing circuit (13, 50) generates a second output which controls impedance of a first variable impedance circuit (32, 70). The first variable impedance circuit (32, 70) conducts the device current and limits device current flowing through the process control device (24) to a predetermined range. A potential sensing circuit (18, 94) in the reverse current protection circuit (20, 54) senses a potential induced across the process control device (24) and generates a third output which is indicative of polarity of device current. The third output controls impedance of a second variable impedance circuit (30, 56) which also conducts the device current. The second variable impedance circuit (30, 56) reduces the flow of reverse polarity current through the process control device (24) while having little effect on normal operation of the process control instrument (10).



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<sup>+</sup> It is not yet known for which States of the former Soviet Union any designation of the Soviet Union has effect.

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PROCESS CONTROL INSTRUMENT  
WITH LOOP OVERCURRENT CIRCUIT  
BACKGROUND OF THE INVENTION

This invention relates to industrial process  
5 control instruments such as pressure transmitters,  
current to pressure (I/P) converters, and the like  
having overcurrent and reverse current protection  
circuits.

In industrial process control systems,  
10 overcurrent and reverse current protection circuits  
operate between a two-wire DC current loop and a process  
control instrument. These protection circuits reduce  
the incidence of damage or degradation to the process  
15 control instrument from excessive and reverse polarity  
currents from the loop. Examples of such process  
control instruments include pressure, temperature, flow,  
pH, conductivity and the like transmitters, are shown  
for example in US-A 3975719, and current to pressure  
20 converters, valve actuators and the like, are shown for  
example in US-A 4481967, both assigned to the owner of  
the present application.

Although a variety of operating ranges are  
used, two wire transmitters and I/P's typically operate  
in a loop current range of 4 to 20 mA, where loop  
25 current flows in one continuous loop. Energization of  
the loop is typically limited to a lower energy level  
incapable of igniting a combustible atmosphere.  
Therefore, since process control instruments operate  
remotely from control centers, the potential drops  
30 induced in each of the loop wires supplying loop current  
and the process control instrument are critical in  
determining a maximum wire length for remote operation  
of the process control instrument. The application of

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process control instruments in the industrial process industry requires careful consideration of several system design parameters including lift-off potential of the process control instrument, which is desired to be reduced. Lift-off potential is a minimum potential necessary at an instrument to ensure that the process control instrument operates properly. Reducing potential drops of the overcurrent and reverse current protection circuits, each of which increase the lift-off potential of the process control instrument, allows for an increased potential drop in the loop wire thus increasing permissible wire length.

Some instruments include a diode in series with the two wire loop to block the flow of reverse current, as taught in US-A 3975719 and US-A 4783659 for two wire transmitters, both assigned to the owner of the present application. The diode produces a large potential drop in the instrument when current flows in the proper direction, which significantly increases the lift-off voltage and reduces the permissible wire length.

US-A 3975719 and US-A 4783659 also teach overcurrent protection circuits in two wire current transmitters. These Patents teach a resistor in series with the two wire loop and connected to the emitter of a transistor with one end of a Zener diode connected to a remote end of the resistor and the other end of the Zener diode connected to the base of the transistor. While this combination limits the maximum value of the loop current, a large potential drop is produced across the resistor during normal operation which further contributes to increasing the lift-off potential of the process control instrument.

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There is a need to provide a protection circuit that protects a process control instrument from large and reverse polarity currents from a loop where the currents can damage or degrade the instrument, while  
5 reducing the potential drop in the loop thus reducing a lift-off potential of the instrument. Further, there is a need to provide a protection circuit which diverts substantially no current back to the loop during normal operation thus improving accuracy of the instrument, in  
10 a simple, reliable and cost effective manner. A circuit that is substantially undamaged by either a decreased impedance or a short circuit of the two wire loop is desirable.

In the present invention, a process control  
15 instrument includes overcurrent and reverse current protection circuits, having reduced potential drops and reduced leakage currents, to reduce incidence of damage or degradation to a process control instrument, such as a pressure, temperature, flow, pH, or conductivity  
20 transmitter; or a current to pressure (I/P) converter, a valve actuator, or the like.

The overcurrent protection circuit receives a DC loop current from a two wire loop and passes a portion of the loop current through the process control  
25 instrument as a device current. First current sensing means conducting the device current between the loop and the device provides a first output indicative of the device current amplitude. Current diverting means coupled across the two wire loop responds to the first  
30 output when device current flows at an upper limit by diverting a portion of the loop current back to the loop as a shunt current. Second current sensing means conducts the shunt current and provides a second output

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indicative of the shunt current amplitude. First impedance means having a first variable impedance conducting the device current responds to the second output by varying the first impedance to limit the device current to no greater than a predetermined upper limit.

The reverse current protection circuit conducts the device current between the loop and the process control device and responds to the loop potential. The circuit has second impedance means having a second variable impedance for inhibiting the device current from flowing through the device when the loop potential is reversed from a predetermined polarity. The circuit diverts substantially no device current back to the loop when loop potential comprises a proper polarity and loop current is within the predetermined normal range.

Reference is made to the drawings wherein:

FIG. 1 is a block diagram representation of a first embodiment of a two-wire process control instrument having an overcurrent and reverse current protection circuit according to the present invention; and

FIG. 2 is a schematic representation of a second embodiment of a process control instrument having an overcurrent and reverse current protection circuit according to the invention.

Referring to FIG. 1 a block diagram of a first embodiment of two-wire process control instrument 10 is shown. Instrument 10 is wired in series with power source 44 and a separate process control device 42 to form two-wire loop 11 carrying a DC loop current. Under fault conditions, loop current or voltage in such

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instruments can exceed a predetermined normal range, e.g. 0-60 mA for a 4-20 mA loop where 60 mA is an upper limit, which would damage or degrade performance of process control device 24, such as a pressure transmitter. To reduce incidence of damage or degradation to process control device 24 from excessive and reverse polarity current, instrument 10 includes protection circuit 17 coupling current from loop 11 to device 24. Protection circuit 17 receives DC loop current  $I_1 + I_2$  and passes only normal current or device current  $I_1$  of the loop current on to device 24. Circuit 17 limits device current  $I_1$  to a level in the normal range which prevents or reduces degradation of device 24. The remainder of the loop current, shunt current or overcurrent  $I_2$ , is shunted back to loop 11 for controlling the level of device current  $I_1$ . Shunt current  $I_2$  is substantially zero until amplitude of normal current  $I_1$  attains the upper limit in the normal range.

Process control device 24, such as a pressure transmitter as disclosed, senses process variable "PV" as illustrated in FIG. 1. Process control device 24 controls amplitude of variable normal current  $I_1$  as a function of amplitude of process variable PV and process control device 42 functions as a current sensing instrument, such as a recorder, by sensing amplitude of loop current  $I_1 + I_2$ , and correlating loop current amplitude to the process variable PV.

On the other hand, process control device 24 can be an output device, such as a current-to-pressure(I/P) converter or a current-to-position converter. In this embodiment, the separate process current control device 42, such as a controller,

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controls amplitude of loop current  $I_1+I_2$ , and process control device 24 controls the magnitude of its output, process variable PV, as a function of amplitude of variable normal current  $I_1$ .

5           The process control device 24 can also include a circuit for generating and receiving a time-varying-signal sent over loop 11 such as taught in US-A 4665938 to Brown et al.

10           The present invention is suitable for use in a process control system utilizing multidrop process instruments, such as pressure transmitters, each connected in parallel across a two wire loop and processing information by superimposing digital data over a DC line.

15           Loop 11 provides loop current  $I_1+I_2$  to terminal 12 in instrument 10, which returns loop current to loop 11 from terminal 40 in instrument 10. In instrument 10, overcurrent protection circuit 16 and reverse current protection circuit 20 isolate process  
20           control device 24 from excessive currents from the loop 11. Loop current  $I_1+I_2$  flows from terminal 12 to node A in overcurrent protection circuit 16. At node A, any overcurrent  $I_2$  flows to current sensing means 13, while normal current  $I_1$  flows to node B in reverse current  
25           protection circuit 20, as will be explained later. From node B, normal current  $I_1$  flows on to terminal 22 of process control device 24. Normal current  $I_1$  flows through process control device 24 back through terminal 26 of process control device 24 to conductor 31. Normal  
30           current  $I_1$  flows from conductor 31 through reverse current protection circuit 20 to conductor 33 and on through overcurrent protection circuit 16 to node C of overcurrent protection circuit 16. At node C,



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overcurrent  $I_2$  from current diverting means 38 is summed with normal current  $I_1$  such that the entire loop current  $I_1 + I_2$  flows from node C out through terminal 40 back to loop 11.

5           Normal current  $I_1$  flowing through process control device 24 induces potential  $V_2$  across terminals 22 and 26. Potential  $V_2$  is representative of polarity of loop current  $I_1 + I_2$ . Potential sense means 18 coupled across a portion of loop 11 senses potential  $V_2$  and  
10           generates output 3 indicative of potential  $V_2$ . Potential sense means 18 diverts substantially no device current  $I_1$  back to loop 11 when loop potential  $V_2$  is a proper polarity. When potential sense means 18 senses loop potential  $V_2$  to be the proper polarity, impedance  
15           of variable impedance 30 is reduced in response to output 3 and normal current  $I_1$  flows freely through process control device 24 and through variable impedance means 30 to overcurrent protection circuit 16. When, instead, potential sense means 18 senses potential  $V_2$  as  
20           reversed from the proper polarity or insufficient in magnitude, then impedance of variable impedance 30 is increased in response to output 3 thus reducing normal current  $I_1$  flowing through process control device 24 and variable impedance means 30. Thus, reverse current  
25           protection circuit 20, having variable impedance 30 conducting device current  $I_1$ , is responsive to output 3 which is a function of a loop potential  $V_2$ , the protection circuit 20 diverting substantially no device current  $I_1$  back to loop 11 when loop potential  $V_2$  is the  
30           proper polarity.

Amplitude of normal current  $I_1$  flowing through current sense means 34 controls the level of output 1. The variable impedance of current diverting means 38 is

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responsive to the level of output 1. When normal current  $I_1$  flows at the predetermined upper level, output 1 reaches a level such that the impedance of current diverting means 38 is reduced so that shunt current  $I_2$  now flows through current diverting means 38 and also through current sense means 13, which is in series with current diverting means 38. The amplitude of shunt current  $I_2$  flowing through current sense means 13 controls the level of output 2. The level of output 2, which is indicative of shunt current  $I_2$ , controls the impedance of variable impedance 32. The impedance of variable impedance 32 controls the amplitude of normal current  $I_1$  flowing from loop 11 in series through process control device 24 and variable impedance 32 such that normal current  $I_1$  does not exceed the predetermined normal range.

Hence, overcurrent protection circuit 16, which senses the magnitude of device current  $I_1$ , prevents device current  $I_1$  from exceeding a predetermined upper limit which can damage or degrade the performance of process control device 24 even when loop current exceeds the predetermined upper limit. Further, the circuit induces a reduced potential drop in the two wire loop. Moreover, the circuit is relatively insensitive to the impedance of the additional device 42.

FIG. 2 shows a schematic diagram of a second embodiment of two-wire process control instrument 46 wired in series with power source 44 and process control device 42 to form two-wire loop 43 carrying a DC loop current. Instrument 46 comprises overcurrent protection circuit 52, reverse current protection circuit 54 and process control device 24 where the two circuits are

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interposed between the loop 43 and the process control device 24. Overcurrent protection circuit 52 passes only normal current or device current  $I_1$  of loop current through reverse current protection circuit 54 to process control device 24. The remainder of the loop current, shunt current or overcurrent  $I_2$ , is shunted by overcurrent protection circuit 52 back to loop 43. Overcurrent  $I_2$ , as described later, generates an output which controls the impedance between nodes D and E to maintain the level of normal current  $I_1$ , which flows between nodes D and E, in the normal range. Overcurrent  $I_2$  is substantially zero until device current  $I_1$  attains the predetermined upper limit.

Two-wire loop 43 provides varying DC loop current  $I_1 + I_2$  to terminal 12 of overcurrent protection circuit 52. Loop current  $I_1 + I_2$  flows from terminal 12 to node A. At node A, shunt current  $I_2$  flows to resistor 50, while normal current  $I_1$  flows to node B in reverse current protection circuit 54. At node B, normal current  $I_1$  is passed on to terminal 22 of process control device 24. Normal current  $I_1$  flows through process control device 24 to terminal 26 of process controlling device 24 and on to node D. Normal current  $I_1$  flows from node D through node E to node C in overcurrent protection circuit 52. At node C, shunt current  $I_2$  from transistor 68 is summed with normal current  $I_1$  such that the entire loop current  $I_1 + I_2$  flows from node C out through terminal 40 of process control instrument 10 back to loop 43.

Normal current  $I_1$  flowing through process control device 24 induces potential  $V_2$  across terminals 22 and 26. Potential  $V_2$  is representative of polarity of loop current  $I_1 + I_2$ . Enhancement type field-effect

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transistor (FET) 56 coupled across terminals 22 and 26 senses polarity of potential  $V_2$  via resistor 94 across gate 80 and source 82. Substantially no device current is diverted back to loop 43 from gate 80 to source 82, unlike the leakage from a base to an emitter if a bipolar transistor were substituted for FET 56. Leakage current reduces the accuracy of process control instruments and is undesirable. When loop current  $I_1 + I_2$  is of correct polarity, FET 56 is enhanced by potential  $V_2$  and is turned on, where impedance across source 82 to drain 84 is substantially reduced to zero such that normal current  $I_1$  flows freely through process control device 24 and FET 56 from source 82 to drain 84. Substantially no potential drop is induced in loop 43 by reverse current protection 54 when FET 56 conducts device current  $I_1$  since impedance from source 82 to drain 84 is substantially zero in comparison with other loop impedances. When loop current  $I_1 + I_2$  is reversed from the correct polarity such that damage to process control device 24 could occur, FET 56 operates in a depletion mode and is turned off, such that impedance from source 82 to drain 84 is increased thus substantially reducing normal current  $I_1$  flowing through process control device 24.

Reverse current protection circuit 54 operates independently from overcurrent protection circuit 52 and can be interposed between loop 43 and overcurrent protection circuit 52 and conducting the loop current  $I_1 + I_2$ . It can also be interposed between loop 43 and process control device 24 when overcurrent protection circuit 52 is omitted thus conducting device current  $I_1$  which here is the same as the loop current.

Normal current  $I_1$  flowing from node E to node

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C through current sensing resistor 60 induces potential  $V_4$  which is indicative of the amplitude of normal current  $I_1$ . When normal current  $I_1$  attains the upper limit of the normal operating range, potential  $V_4$  across base 68 to emitter 66 biases current diverting means bipolar transistor 62 on, which can also be a FET or the like. Biasing transistor 62 on allows shunt current  $I_2$  to flow from node A through current sensing resistor 50, transistor 62 via collector 64 to emitter 66, and resistor 90 to node C. Shunt current  $I_2$  induces potential  $V_5$  across resistor 50 which is indicative of the amplitude of shunt current  $I_2$ . Resistor 50 can also comprise other current sensing means that generates a potential corresponding a current, such as a transistor. Potential  $V_5$  generates potential  $V_6 = V_1 - V_5 - V_4$  across gate 74 and source 76 such that enhancement type FET 70, serving as a variable impedance, operates in a depletion mode and is turned off.

When FET 70 operates in the depletion mode, impedance from drain 72 to source 76 is substantially increased and substantially all normal current  $I_1$  flows from node D to node E through current limiting means resistor 58 instead of through FET 70 via the drain 72 to source 76, which is in parallel with resistor 58. Resistor 58, or equivalent high impedance current limiting means, has a large power rating for dissipating a large amount of power when conducting the majority of device current  $I_1$ . Resistor 58 has a value such that the sum of potentials  $V_2$ ,  $V_7$  and  $V_4$  induced by normal current  $I_1$  flowing at the upper limit is equal to terminal potential  $V_1$ , thus limiting normal current  $I_1$  to the upper limit. FET 70 can be substituted by a bipolar transistor; however, leakage current across the

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base to emitter of the bipolar transistor degrades accuracy of instrument 46.

When amplitude of normal current  $I_1$  is below the upper limit of the normal range induced potential  $V_4$  is insufficient to bias transistor 62 on, substantially no shunt current  $I_2$  conducts through resistor 50, potential  $V_5$  is substantially zero and FET 70 is enhanced and turned on. Enhanced FET 70 has a reduced impedance of substantially zero from drain 72 to source 76 and substantially all normal current  $I_1$  flows from node D to node E through FET 70 via drain 72 to source 76, instead of through resistor 58, and potential  $V_7$  is reduced to substantially zero. Thus, the parallel combination of FET 70 and resistor 58 functions as a variable impedance inducing a reduced potential drop for limiting device current  $I_1$  to the normal range, and is responsive to potential  $V_5$ , which is indicative of shunt current  $I_2$ . During normal operation, the only substantial potential drop induced in loop 43 by overcurrent protection circuit 52 is  $V_4$ , which is substantially less than a potential drop of a typical forward biased diode. All other components require only minimal wattage ratings thus reducing cost, size requirements and increasing reliability. Further, overcurrent protection circuit 52 operates independently of the impedance of power source 44, and does not highly stress any components while conducting normal current  $I_1$  flowing at the upper limit.

Amplitude of normal current  $I_1$  below the upper limit generates a substantially reduced lift-off potential  $V_1 = V_2 + V_4 + V_7$  compared to conventional protection circuits. Process control instruments having reduced lift-off potentials, such as the invention

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disclosed, are very useful for the industrial process control industry. First of all, the likelihood of generating sparks across terminals 12 and 40, which may ignite a combustible atmosphere, is reduced. Secondly, instrumentation with lower lift-off potentials increase the distance that a remote process control instrument can be located while operating from a safe power source level, such as that produced by power source 44. Protection circuits in process control instruments, such as the invention disclosed, that divert substantially no device current back to the loop during normal operation improve the accuracy of process control instruments.

Resistor 92, connected from node E to base 68 of transistor 62, along with resistors 90 and 94, provide intrinsic safety protection for overcurrent protection circuit 52 and reverse current protection circuit 54. The circuits, as disclosed, have no components capable of substantial energy storage, such as a capacitor or an inductor, that are capable of discharging with sufficient energy to provide a spark which can ignite an explosive atmosphere.

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WHAT IS CLAIMED IS:

1. A process control instrument, comprising:  
a process variable controlling device  
receiving a device current; and  
a current protection circuit receiving a loop  
current from a two wire loop and passing  
a portion of the loop current as the  
device current through the device no  
greater than a predetermined upper  
limit, comprising:  
first current sensing means conducting  
the device current between the loop  
and the device for generating a  
first output indicative of the  
device current;  
current diverting means coupled across  
the loop responsive to the first  
output for diverting a portion of  
the loop current as a shunt current  
back to the loop through a second  
current sensing means for  
generating a second output  
indicative of the shunt current;  
and  
impedance means having a variable  
impedance conducting the device  
current and responsive to the  
second output for limiting device  
current.
2. The instrument of Claim 1 wherein the second  
output controls the magnitude of the variable impedance.
3. The instrument of either Claims 1 or 2 wherein  
the impedance means enables substantially all loop



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current to flow through the device when the loop current is no greater than the upper limit.

4. The instrument of any one of the preceding claims wherein the first and second current sensing means each comprise a separate resistor.

5. The instrument of any one of the preceding claims wherein the current diverting means comprises a transistor.

6. The instrument of any one of the preceding claims wherein the impedance means comprises a field effect transistor.

7. A process control instrument, comprising:  
a process variable controlling device  
receiving a device current from a two  
wire loop; and

a reverse current protection circuit  
conducting the device current between  
the loop and the device, the protection  
circuit having potential sense means  
coupled across the loop for generating  
an output indicative of the sensed loop  
potential, and impedance means having a  
variable impedance conducting the device  
current and responsive to the output for  
inhibiting the device current from  
flowing through the device when the loop  
potential is reversed from a  
predetermined polarity, wherein the  
reverse current protection circuit  
diverts substantially no device current  
back to the loop when loop potential  
comprises the predetermined polarity.

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8. A process control instrument, comprising:  
a process variable controlling device  
receiving a device current; and  
a current protection circuit receiving a loop  
current from a two wire loop and passing  
a portion of the loop current as the  
device current through the device,  
comprising:  
current sensing means conducting the  
device current for generating a sensor  
output indicative of the device current;  
current diverting means coupled across  
the loop and responsive to the sensor  
output for diverting loop current in  
excess of a predetermined upper limit of  
device current back to the loop when the  
sensor output indicates the upper limit  
is reached; and  
reverse current protection means coupled  
across the loop having a first variable  
impedance conducting the device current  
for inhibiting the device current from  
flowing through the device when a loop  
potential is reversed from a  
predetermined polarity, where the device  
current is limited to a current range  
controlled by the first variable  
impedance and the upper limit.
9. The instrument of Claim 8 wherein the current  
diverting means further comprises a second variable  
impedance conducting the device current for limiting the  
device current to no greater than the upper limit.

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10. The instrument of either of Claims 8 or 9 wherein the first variable impedance is responsive to the loop potential and inhibits substantially all device current from flowing through the device when the loop potential is reversed from the predetermined polarity.

11. The instrument of any one of Claims 8, 9 or 10 wherein the current diverting means enables substantially all loop current to flow through the device when loop current is no greater than the upper limit and wherein the first and second variable impedance each comprises a separate field effect transistor, and the current sensing means comprises a resistor.

12. The circuit of anyone of claims 8, 9, 10 or 11 wherein the device current is within a device range of 4 to 20 milliamperes, and the device current and the loop current are substantially equal with the shunt current being substantially zero.

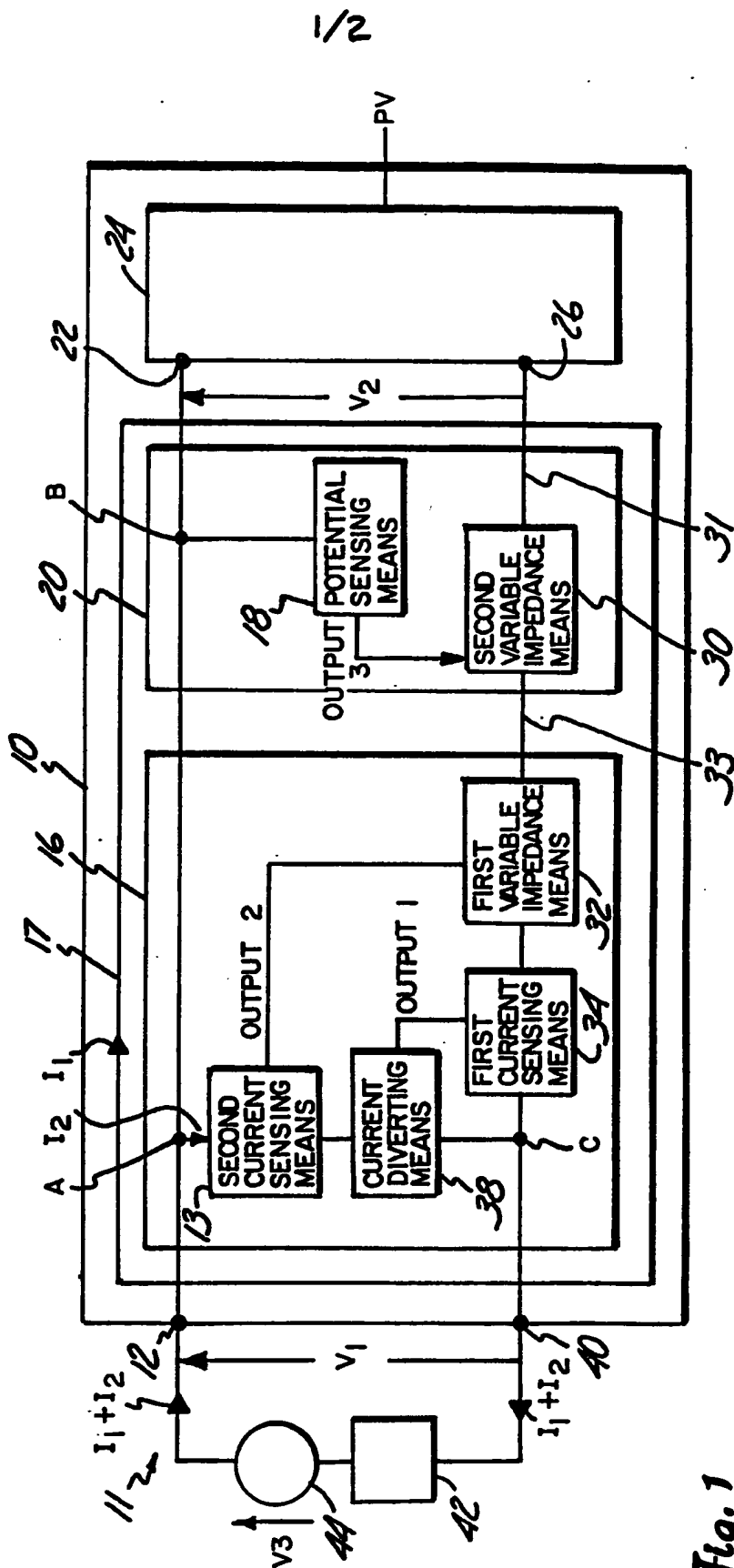
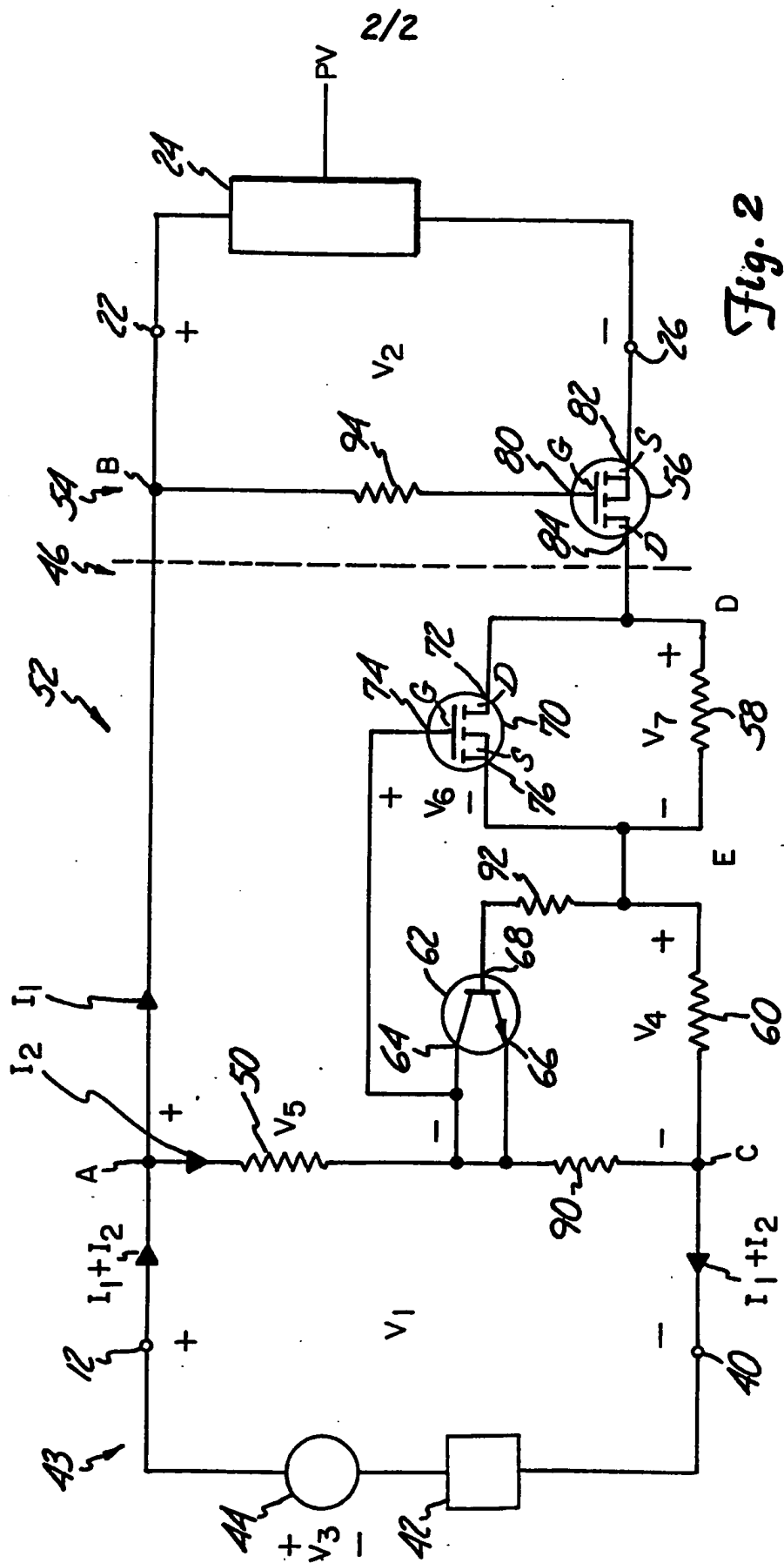


Fig. 1



# INTERNATIONAL SEARCH REPORT

International Application No. PCT/US91/05109

<b>I. CLASSIFICATION OF SUBJECT MATTER</b> <small>Indicate the International Patent Classification (IPC) or to both National Classification and IPC</small>	
INT. Cl. 5 H02H 9/02 U.S. Cl. 361/18,56	
<b>II. FIELDS SEARCHED</b>	
Minimum Documentation Searched	
Classification Symbols	
U.S. 361/18,56,58,91,111,84	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched	

III. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category *	Citation of Document, ** with indication, where appropriate, of the relevant passages †	Relevant to Claim No. ‡
Y	US,A 3,582,713 (TILL) 16 MARCH 1970 see entire document	1-22
Y	US,A 4,857,985 (MILLER) 15 AUGUST 1989 see entire document	1-22

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<b>IV. CERTIFICATION</b>	
Date of the Actual Completion of the International Search  29 OCTOBER 1991	Date of Mailing of this International Search Report  <b>14 NOV 1991</b>
International Searching Authority  ISA/US	Signature of Authorized Officer  TODD E. DEBOER-Primary Examiner